

# **Feasibility and Error Sources for Ocean Surface Salinity Measurements from Space**

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Sea surface salinity (SSS) is a key parameter for studying ocean circulations and global hydrologic budgets. Recent studies have shown that assimilating SSS combined with other parameters has a positive impact on coupled forecasts. In addition, the ocean rainfall is reflected in the SSS variability, enabling estimates of ocean rainfall from SSS to balance surface freshwater flux in the climate prediction models. The ocean surface salinity has been viewed as a missing element in satellite ocean observations.

The principles of satellite SSS remote sensing are based on the sensitivity of sea surface brightness temperatures (Tb) to SSS. The sea surface Tb is a function of the water dielectric constant and surface temperature (SST). The water dielectric constant, influencing the emissivity of sea surfaces, is a function of salinity, temperature, and radio frequencies. The 1.4 GHz (L-band) frequency band set aside for radio astronomy use is considered to be adequate for SSS remote sensing. However, the L-band sea surface Tb is influenced by many other geophysical parameters, such as sea surface roughness, sea surface temperature, ionospheric Faraday rotation, solar radiation, and atmospheric gases. This paper will describe the effects of these parameters and potential techniques for corrections. We also describe space mission concepts for global SSS measurements.

To investigate the feasibility of SSS remote sensing with an accuracy of 0.2-0.3 psu required for weekly global mapping of open oceans, the aircraft Passive Active L/S (PALS) microwave instrument has been developed by the Jet Propulsion Laboratory (JPL). This instrument is a dual-frequency, dual-polarized combined radiometer and radar. This instrument has been flown on the NCAR C-130 with three flights off US east coast across the Gulf Stream and National Data Buoy Center (NDBC) buoys on July 17-19, 1999. The in-situ sea surface salinity was provided by the Cape Hatteras research vessel from Duke University. The PALS dataset has been analyzed to quantify the influence of surface roughness. The data indicate that the excess brightness temperatures due to sea surface roughness can be as high as 1 to 2 Kelvins, which will yield about 2-3 psu SSS errors if uncorrected. The PALS data suggest a linear relationship between the excess brightness temperatures and the radar measurements for the range of wind speed encountered wind (<7 m/s). A linear relationship is consistent with the Bragg scattering theory for sea surfaces, which predicts a linear dependence of the excess brightness temperatures and radar backscatter on the surface wave spectra. The proportional coefficients, estimated from the PALS data, vary with the polarization and frequency. We remove the excess brightness temperatures from the PALS radiometer data with this linear model. The standard deviation of the residual errors is estimated to be less than 0.2 Kelvin. By comparison with the Cape Hatteras SSS data, the SSS retrieval error approaches the accuracy required for open ocean conditions.

# **FEASIBILITY AND ERROR SOURCES FOR OCEAN SURFACE SALINITY MEASUREMENTS FROM SPACE**



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**JET PROPULSION LABORATORY**

**6-10 DECEMBER 1999**

# **OUTLINE**

- **INTRODUCTION**
- **ANALYSIS OF ERROR SOURCES**
- **FEASIBILITY OF SATELLITE SSS RETRIEVAL**
- **AIRCRAFT SSS EXPERIMENT PROGRESS**
- **SUMMARY**

# OCEAN SURFACE SALINITY MISSION SCIENCE MEASUREMENT AND APPLICATIONS OBJECTIVES:

- SCIENCE THEMES
  - Climate Variation and Prediction
  - Global Water and Energy Cycle
- SCIENCE QUESTIONS
  - Exploration What are the large scale salinity anomalies of the ocean?
  - Understanding What is the role of salinity in the global water cycle?
  - Impact What is the impact of salinity on seasonal to decadal climate change?
- DATA PRODUCTS
  - Sensor Data Records (along track swath geometry,  $T_B$ )
  - Geophysical Data Records (along track swath geometry, salinity)
  - Gridded maps (rectilinear coordinates, salinity)

# OCEAN SALINITY MISSION

## SCIENCE MEASUREMENT AND APPLICATIONS

### OBJECTIVES (cont.)

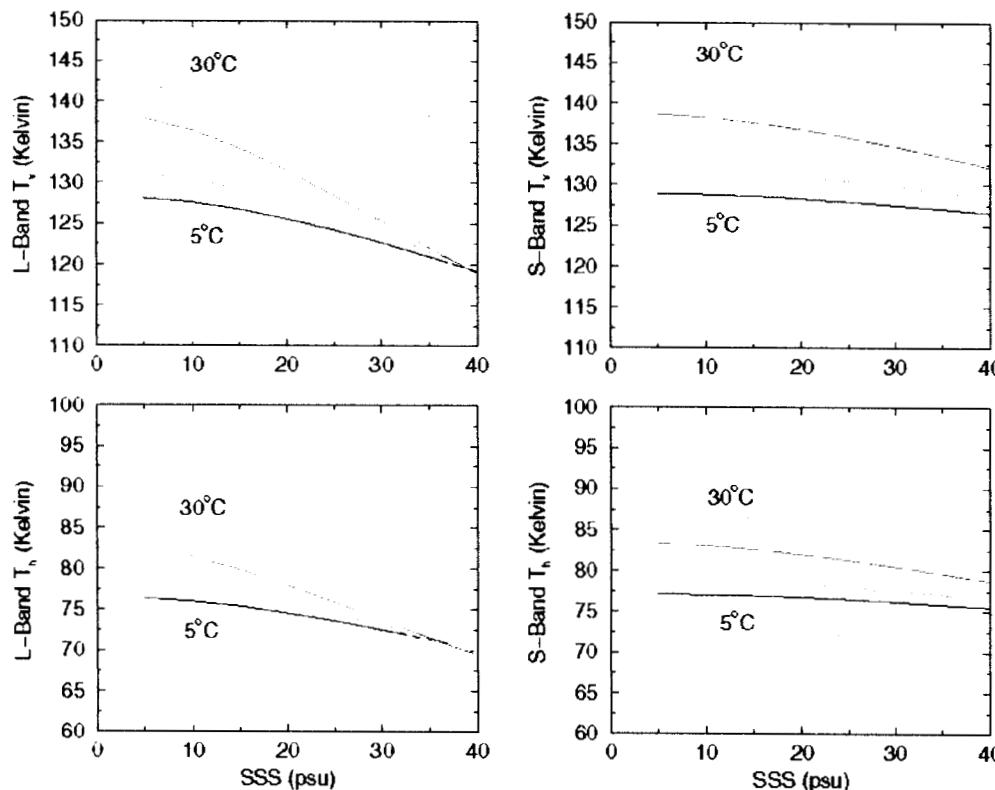
- SCIENCE MEASUREMENT REQUIREMENTS
  - Spatial resolution: <100 km footprint
  - Temporal sampling:
    - repeat global coverage every 2-3 days
    - weekly (or monthly) (gridded maps)
  - Precision / calibration stability:
    - 0.1 - 0.2 K (sensor record)
    - < 1 psu (geophysical record)
    - 0.2-0.3 psu (weekly gridded maps)
    - 0.1-0.2 psu (monthly gridded maps)
- POTENTIAL APPLICATIONS
  - Improving seasonal to interannual [ENSO] climate predictions
  - Improving ocean rainfall estimates and global hydrologic budgets
  - Monitoring large scale salinity events

# **STATUS OVERVIEW**

- A OCEAN SURFACE SALINITY MISSION HAS BEEN INCLUDED IN THE NASA EARTH SCIENCE MISSION PLAN IN 2000+
- JPL IS BEING FUNDED BY THE NASA INSTRUMENT INCUBATOR PROGRAM TO STUDY THE LARGE MESH-DEPLOYABLE TECHNOLOGY
- JPL HAS A FUNDED R&D PROGRAM TO STUDY THE FEASIBILITY AND ALGORITHM WITH AIRCRAFT INSTRUMENTATION
- WILL SUBMIT AN ESSP PROPOSAL IN 2000

# BASIS OF SSS MICROWAVE REMOTE SENSING

- THE SENSITIVITY OF L-BAND (1.4 GHZ) OCEAN SURFACE BRIGHTNESS TEMPERATURES TO THE SEA SURFACE SALINITY ENABLES SPACEBORNE REMOTE SENSING.
  - SSS SENSITIVITY REDUCES WITH INCREASING FREQUENCY
  - VERTICAL POLARIZATION IS MORE SENSITIVE TO SSS THAN HORIZONTAL POLARIZATION
  - BETTER SENSITIVITY FOR WARMER SURFACES
  - SST CAN BE OBTAINED FROM S- OR C-BAND RADIOMETERS



SST (°C)	$\Delta T_v/\Delta SSS$ (K/psu)	$\Delta T_h/\Delta SSS$ (K/psu)
10	0.44	0.30
20	0.65	0.43
30	0.75	0.50

Sensitivity of L-Band Brightness Temperatures to SSS at 45° Incidence Based on Klein and Swift's Model

# OCEAN SALINITY RETRIEVAL STUDY OBJECTIVES

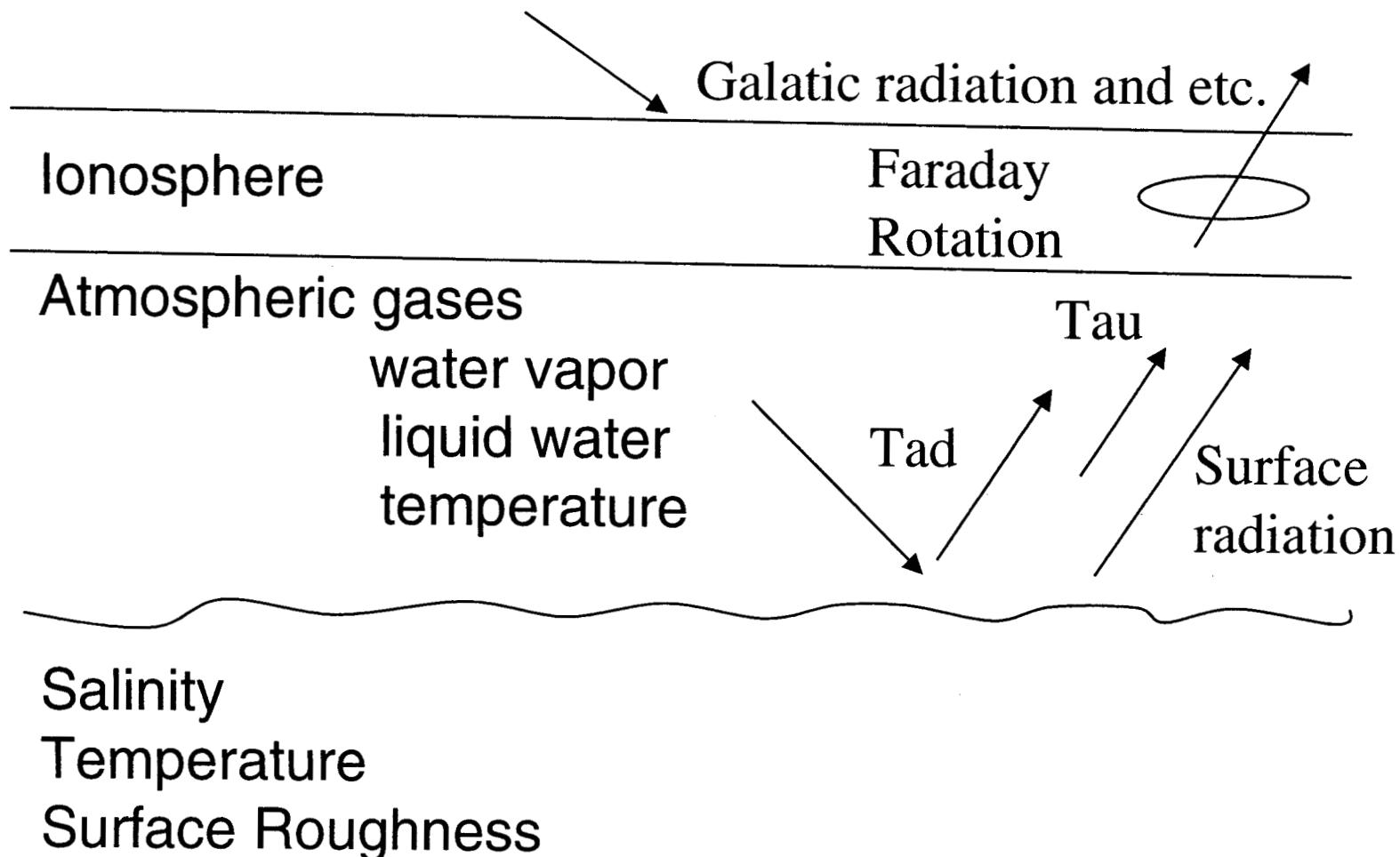
- TO DETERMINE THE ERROR SOURCES FOR SSS MEASUREMENTS
- TO ESTIMATE THE OCEAN SALINITY MEASUREMENT ACCURACY FOR SPACEBORNE SENSORS
  - TO DETERMINE THE CALIBRATION REQUIREMENTS
  - TO DETERMINE THE SCANNING GEOMETRY
    - CONICAL SCANNING VS. CROSS-TRACK SCANNING
- TO STUDY THE RETRIEVAL ALGORITHM

# OCEAN SALINITY RETRIEVAL STUDY APPROACH

- **ANALYSIS OF ERROR BUDGET**
  - RADIOMETER SENSITIVITY
  - CALIBRATION ERROR
  - GEOPHYSICAL MODELING ERROR
- **SALINITY RETRIEVAL SIMULATION**
  - CONFIGURATION PARAMETERS: POLARIZATION, FREQUENCIES, INCIDENCE ANGLES
  - CALIBRATION REQUIREMENT

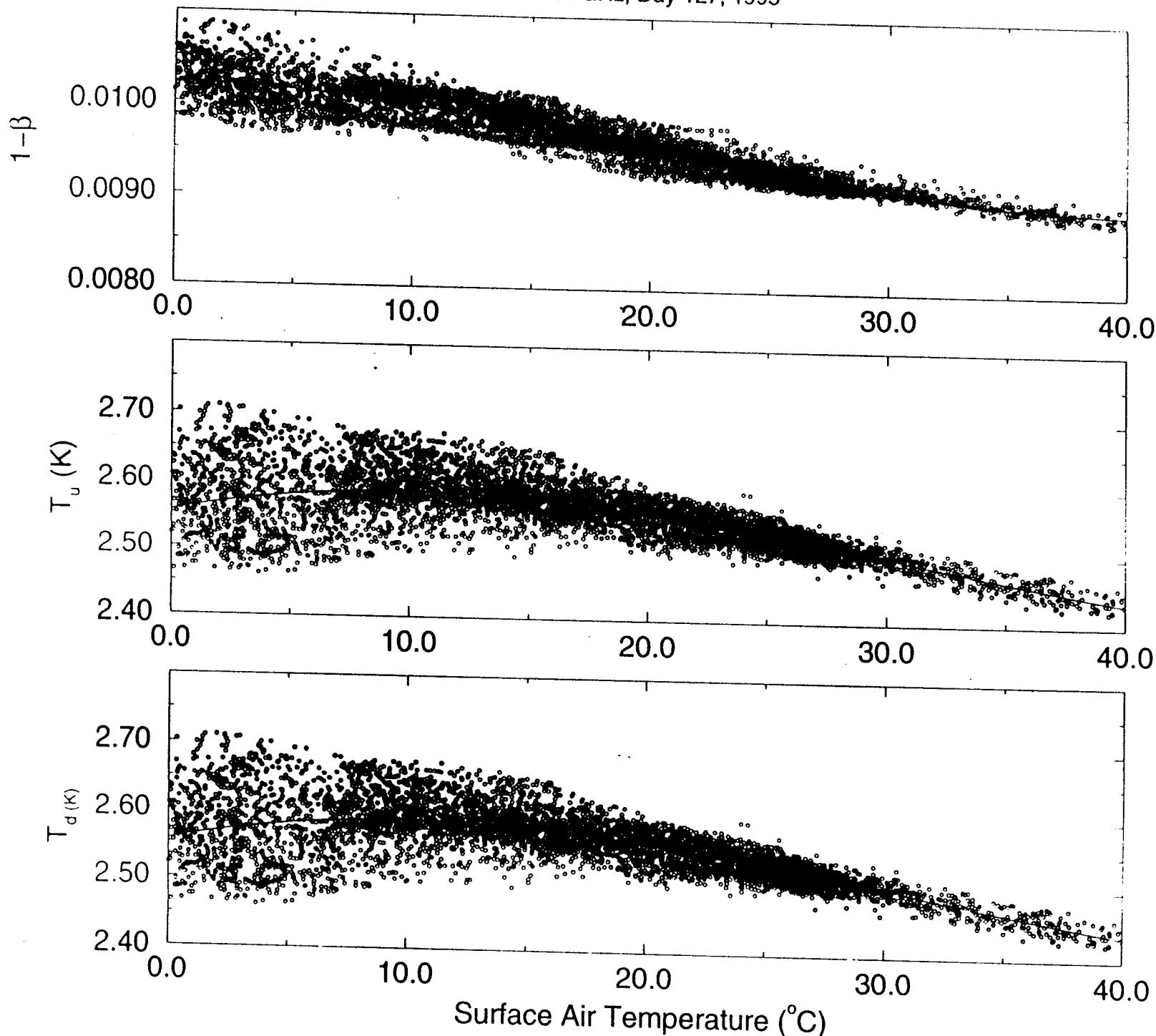
# GEOPHYSICAL CONTRIBUTIONS TO SATELLITE MICROWAVE MEASUREMENT

- Microwave ocean radiation is influenced by



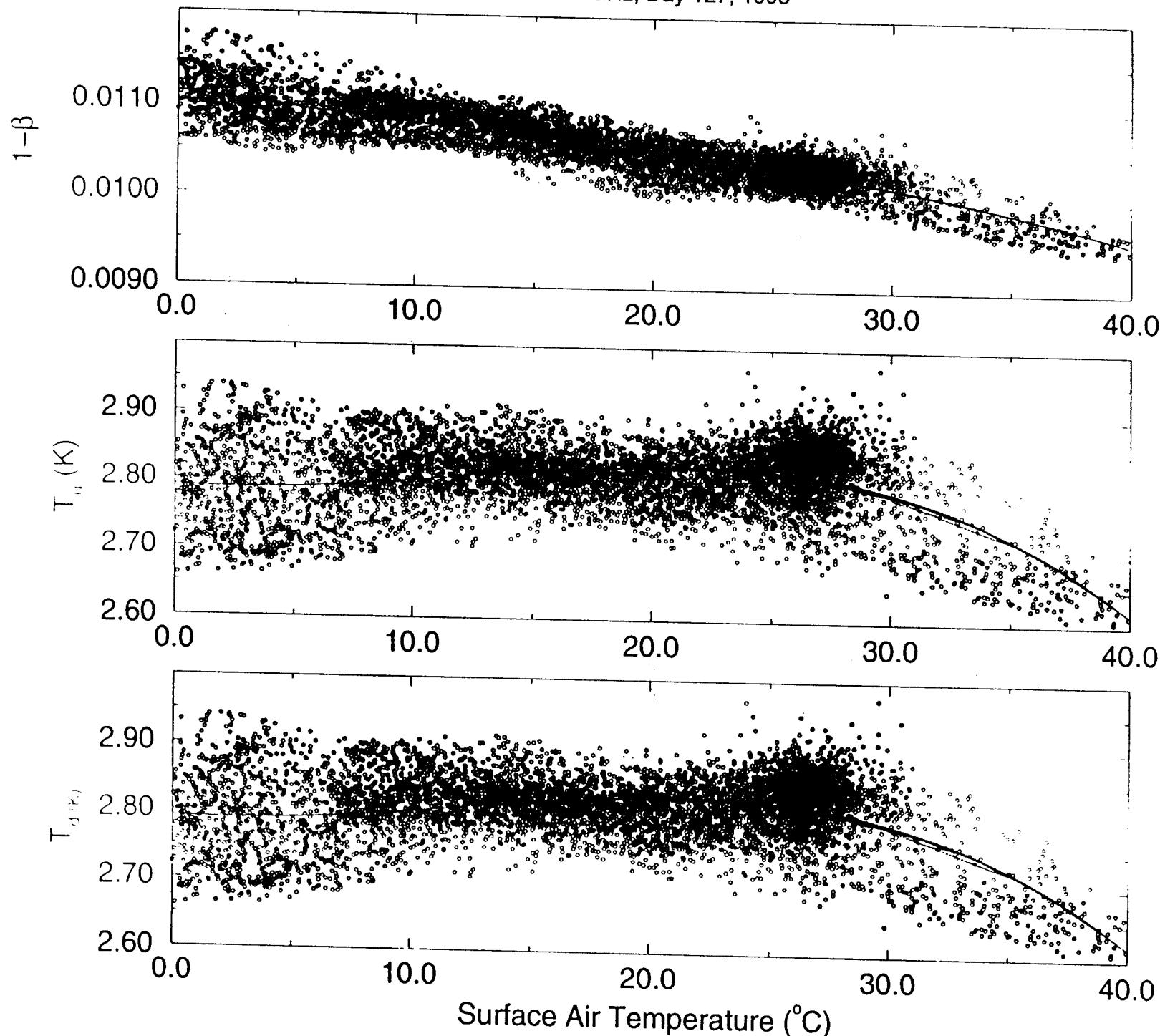
# NMC EFFECTIVE ATMOSPHERIC PARAMETERS

f=1.4 GHz, Day 127, 1995



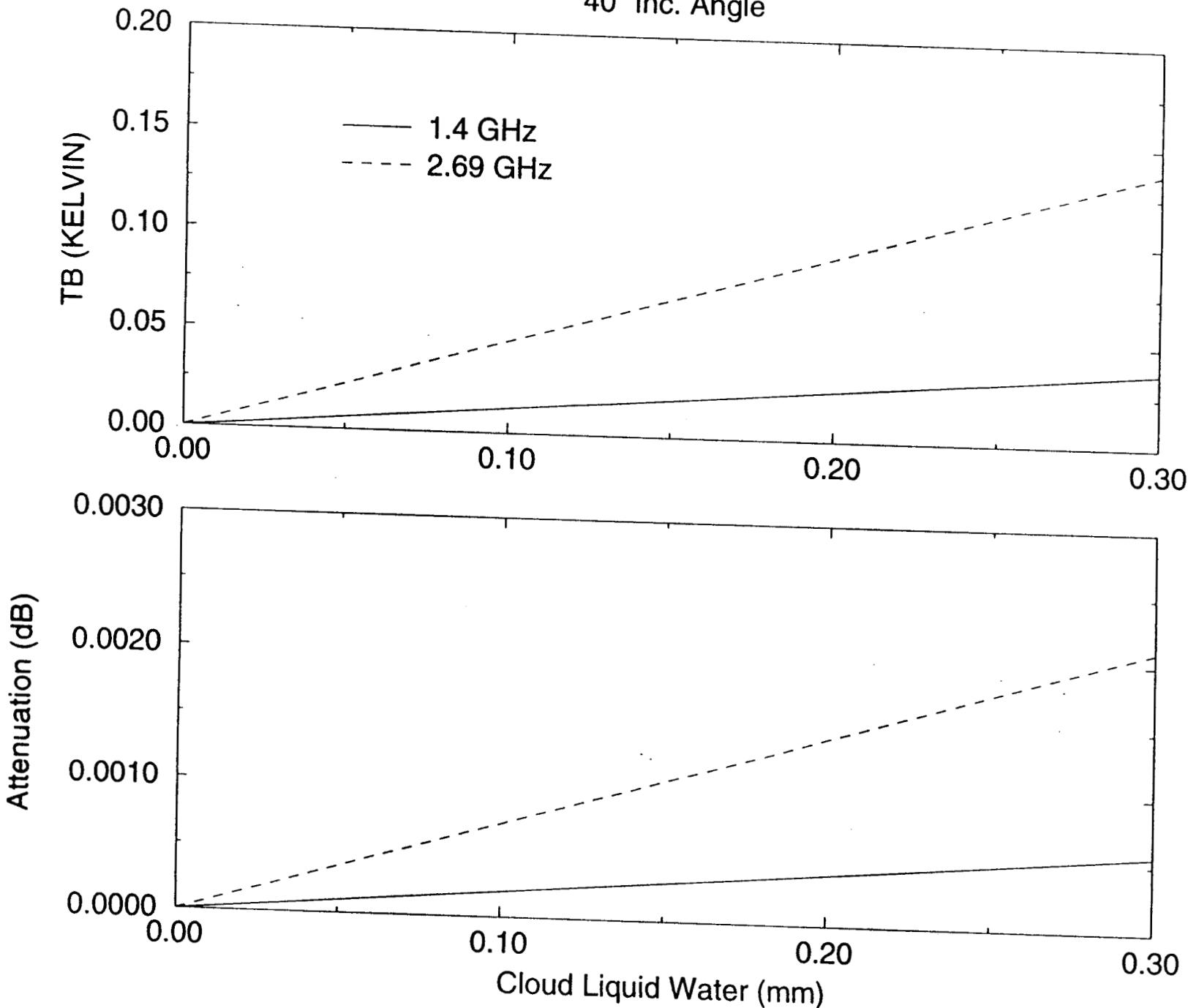
# NMC EFFECTIVE ATMOSPHERIC PARAMETERS

f=2.69 GHz, Day 127, 1995



# CLOUD LIQUID WATER RADIATION AND ATTENUATION

40° Inc. Angle



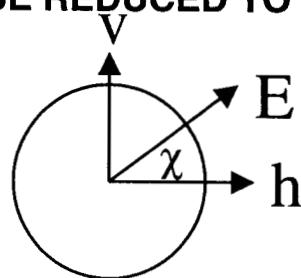
# ATMOSPHERIC MODELING NOISE

- USE LIEBE'S MPM TO STUDY THE ATMOSPHERIC TRANSMITTANCE AND RADIATION AT L (1.28&1.4 GHZ) AND S (2.69&3.1GHZ)
  - 3 NMC ANALYSIS IN MAY 1995
    - GLOBAL HUMIDITY, TEMPERATURE, AND PRESSURE PROFILES
  - SSM/I MONTHLY AVERAGED WATER VAPOR, CLOUD LIQUID WATER, AND CLOUD FRACTION FOR MAY 1995

PARAMETER	DTm (L)		DTm (S)	
LWP(mm)	0	0.2	0	0.2
VAPOR & GASES	0.040	0.040	0.050	0.050
CLOUD (K)	0.000	0.020	0.000	0.070
RSS (K)	0.040	0.045	0.050	0.086

# IONOSPHERE TEC MODELING NOISE

- USE OF GPS NETWORK GLOBAL TEC MEASUREMENTS BEING EVALUATED
  - MAYBE INADEQUATE FOR SOUTHERN OCEANS DUE TO LESS GPS COVERAGE
  - HOW WELL CAN THE TEC BETWEEN THE SURFACE AND SATELLITE AT 600 KM ALTITUDE BE ESTIAMTED FROM GPS TEC?
- ACCURACY OF L-BAND POLARIMETRIC U CHANNEL MEASUREMENTS FOR THE DETERMINATION OF FARADAY ROTATION
  - $T_v$  and  $T_h$  ERRORS CAN BE REDUCED TO LESS THAN 0.08 K.



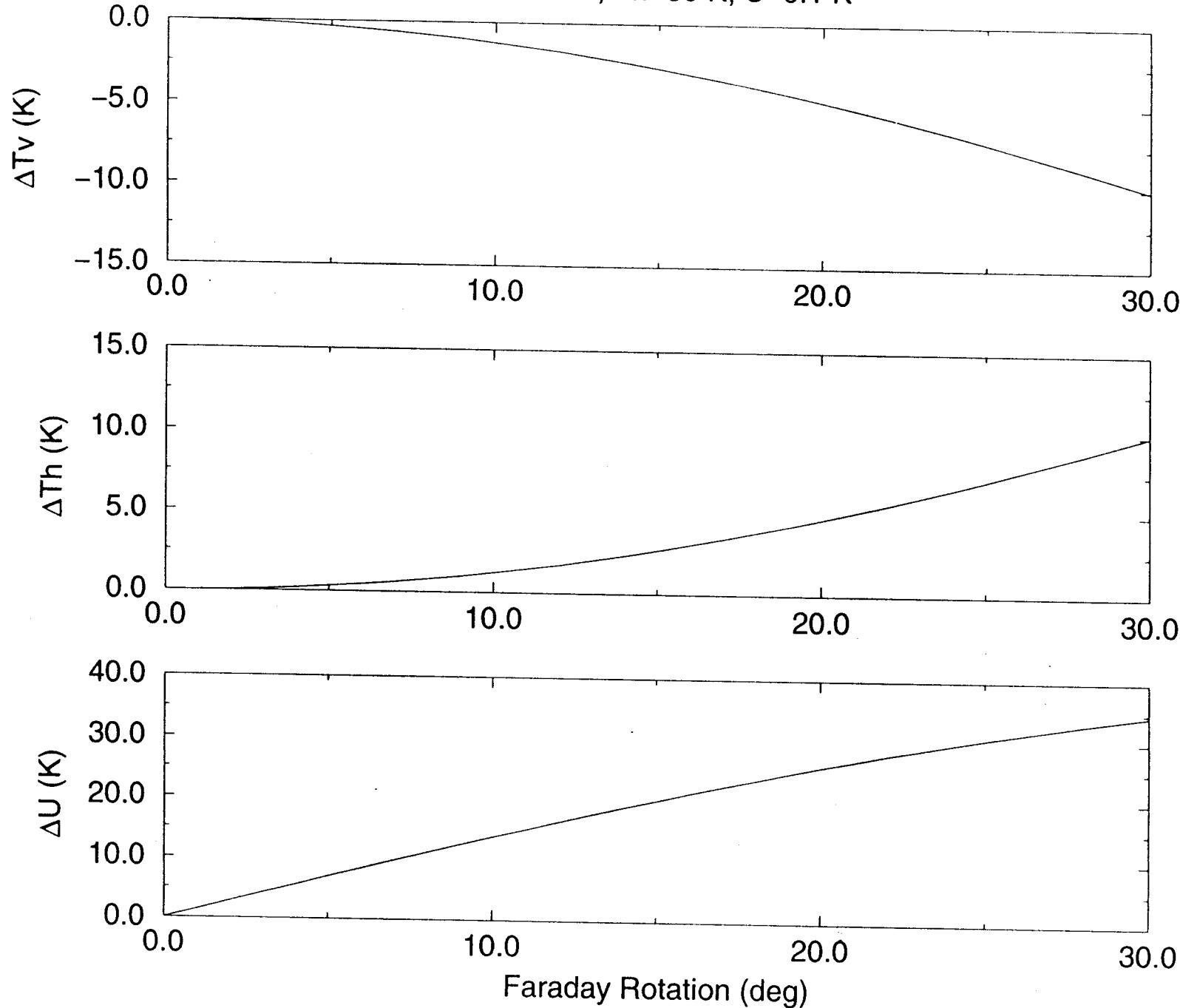
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$\Delta U(K)$	$\Delta \chi$ (deg)	$\Delta T_v, \Delta T_h$ (K)
0.2	<0.15	<0.08

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# EFFECTS OF FARADAY ROTATION ON TB

$T_v=120\text{ K}$ ,  $T_h=80\text{ K}$ ,  $U=0.1\text{ K}$



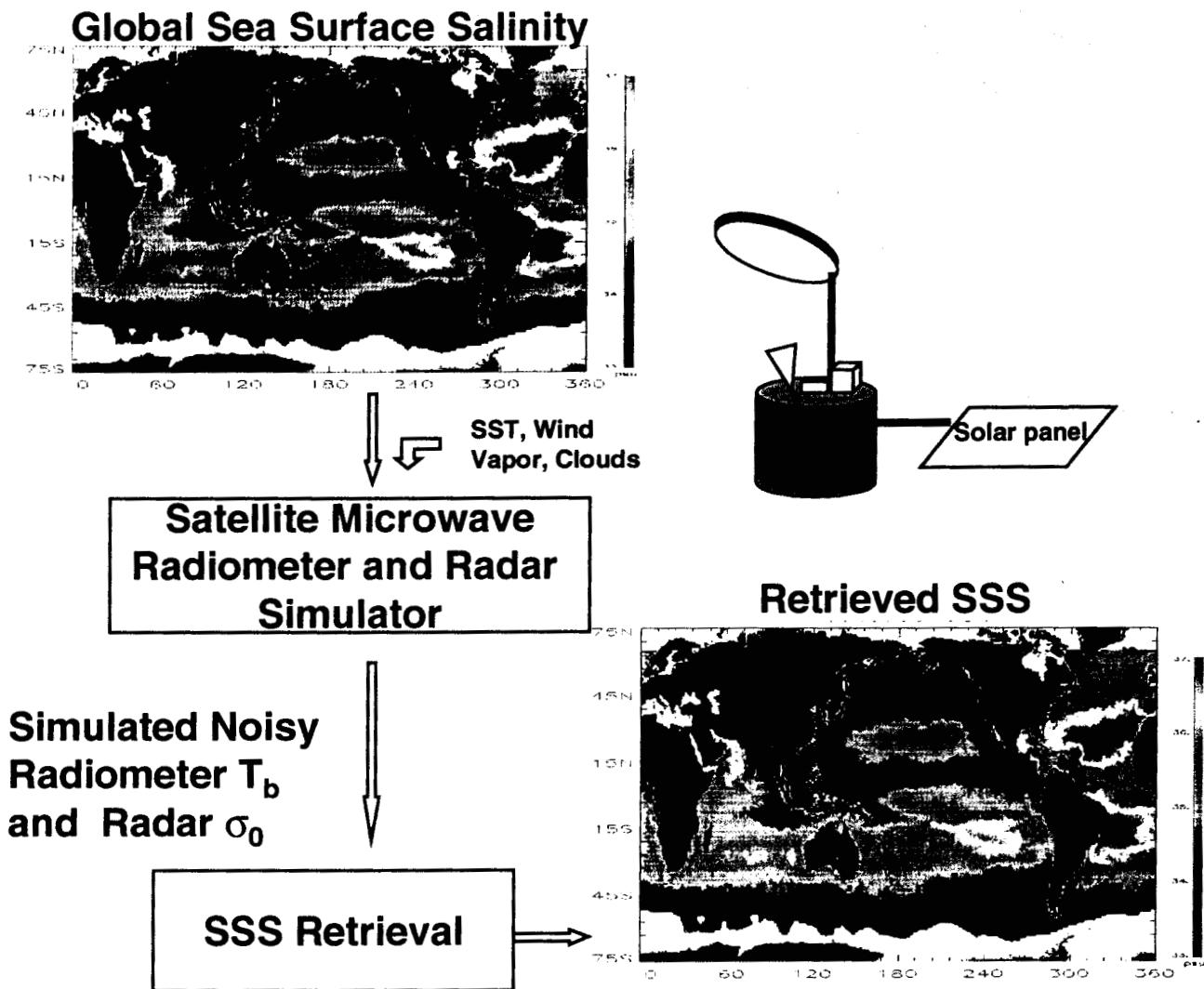
# GEOPHYSICAL MODELING ERROR ALLOCATION AT 1.4 GHz

- KNOWLEDGE ACCURACY
- DATA FLAG IF THE NOISE IS LARGER THAN THE ALLOCATION
- \*ASSUME L-BAND POLARIMETRIC RADIOMETER  
MEASUREMENTS FOR IONOSPHERIC CORRECTION

## ERROR ALLOCATION

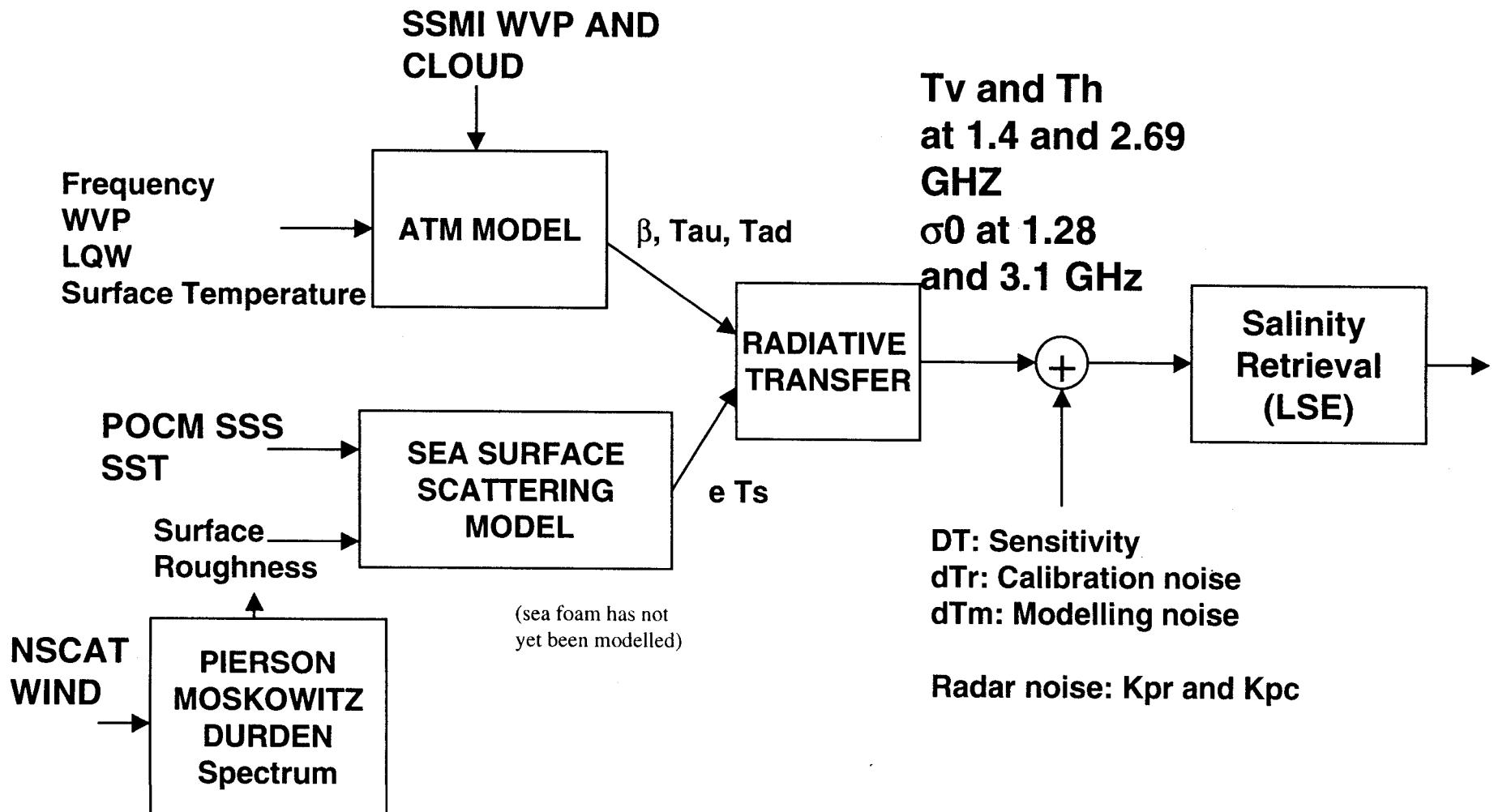
Parameter	dTm (K) 1 sigma
Atmosphere	0.05
Faraday Rotation*	0.08
Solar	0.15
Lunar	0.03
Galactic	0.05
HI	0.02
Surface Roughness	0.1
RSS	0.21

# SSS MISSION FEASIBILITY

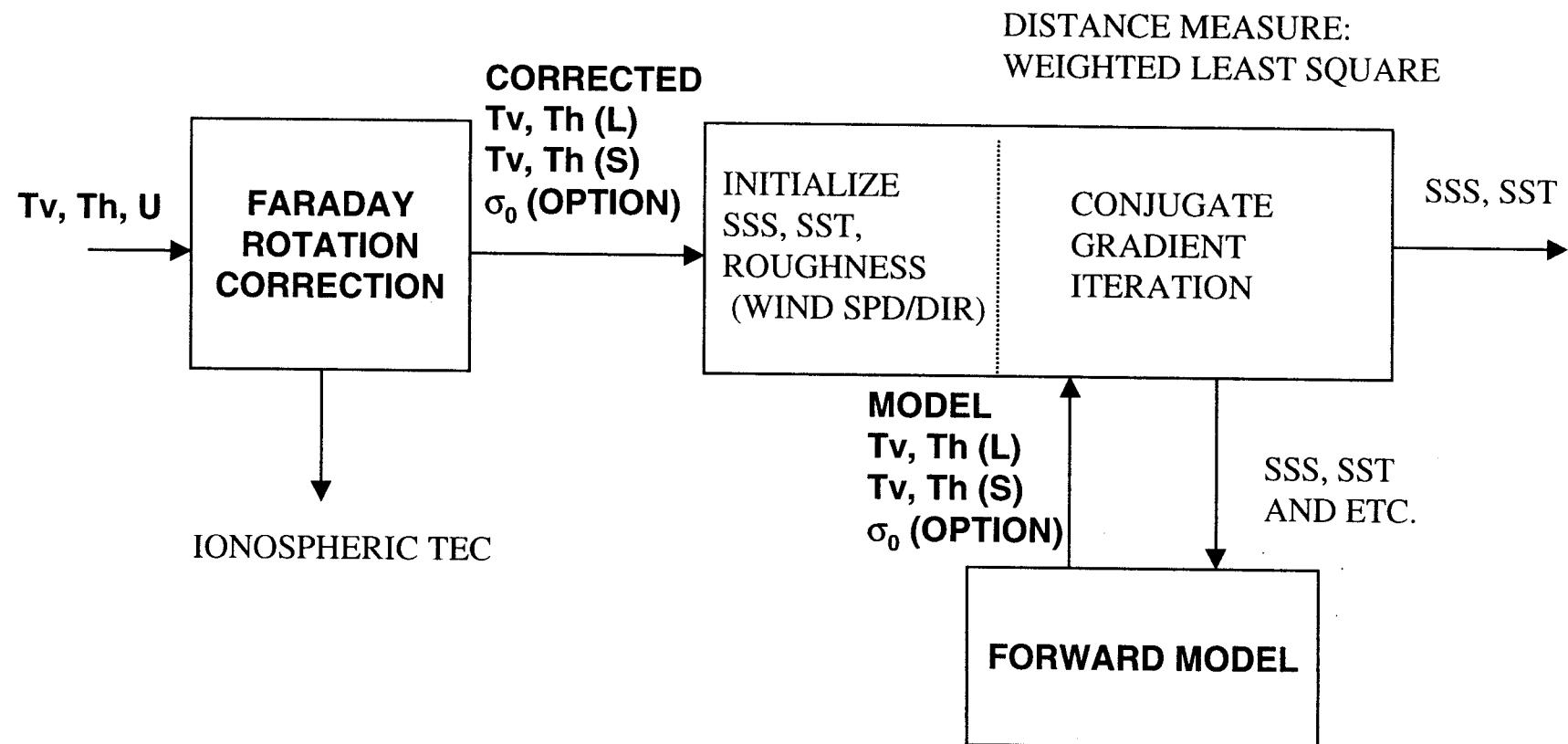


- Sea surface salinity mission simulated with realistic ocean fields for a conical scanning microwave radiometer and radar
- The difference between the input and retrieved SSS fields depends on the instrument calibration errors, instrument sensitivity, and geophysical modeling uncertainty
- Predicted accuracy of 0.2-0.3 psu weekly and 0.1-0.2 psu monthly meets the post 2002 EX-4 sss mission requirements for 0.2 K radiometer and 0.2 dB radar calibration stability.

# OCEAN SALINITY RETRIEVAL SIMULATION



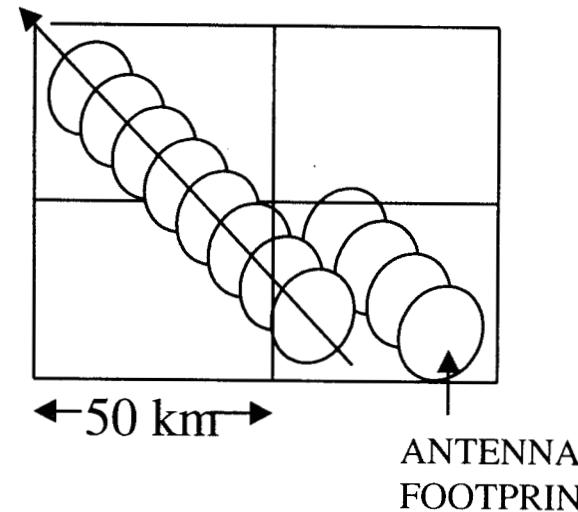
# OCEAN SALINITY RETRIEVAL ALGORITHM



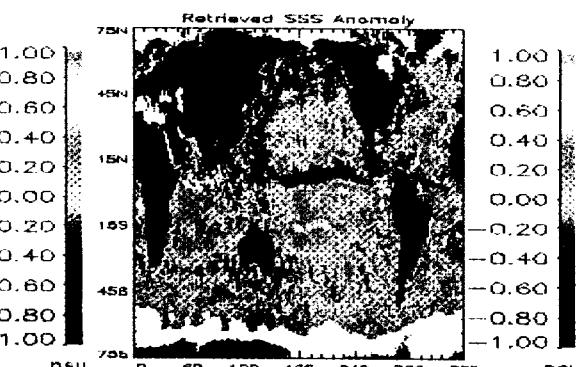
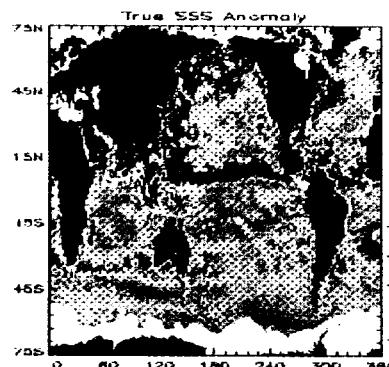
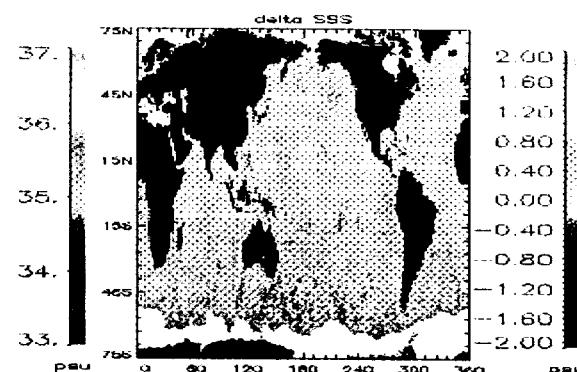
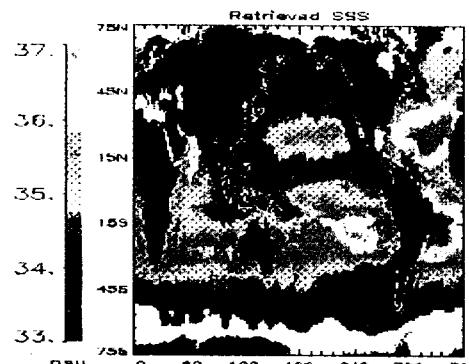
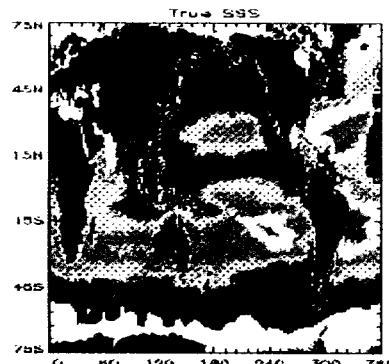
# ERROR BUDGET

- **RADIOMETER NEDT**
  - MODELED BY WHITE GAUSSIAN NOISE
- **CALIBRATION STABILITY  $\Delta T_r$** 
  - MODELED BY TEMPORALLY CORRELATED GAUSSIAN NOISE (4 MIN CORRELATION TIME)
- **GEOPHYSICAL MODELING NOISE  $\Delta T_m$** 
  - SPATIALLY CORRELATED (50 KM CORRELATION LENGTH)

	50km	100km
$\Delta T$ (K)	0.07	0.035
$\Delta T_m$ (K)	0.20	0.1
$\Delta T_r$ (K)	0.20	0.2
RSS (K)	0.29	0.23



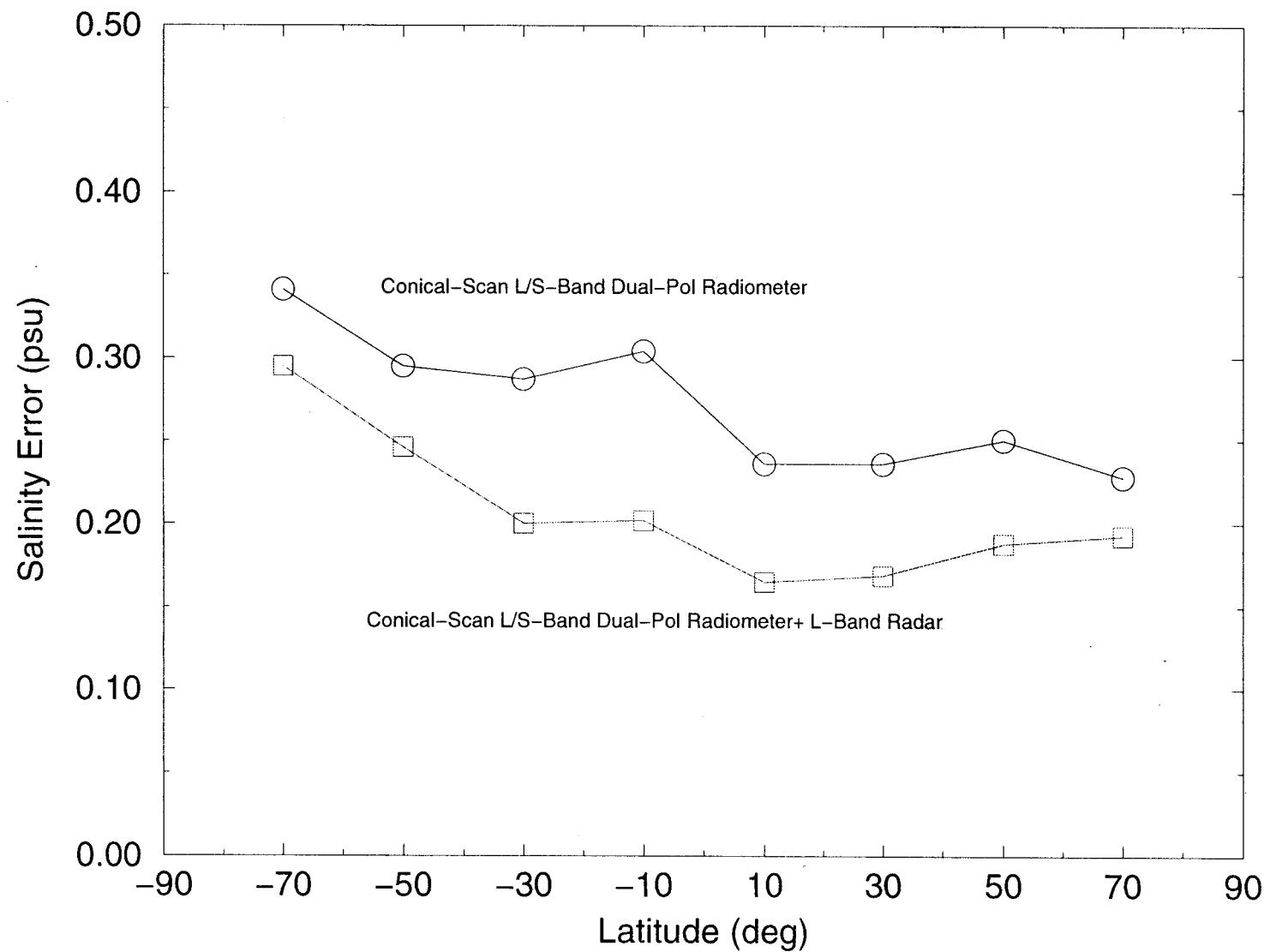
# GLOBAL SSS MISSION SIMULATION



- SSS Mission Performance Simulation with POCM SSS Fields, NSCAT Winds, and SSM/I Fields for September 1996 for a Conical-Scanning Microwave L-band/S-band Dual-Polarized Radiometer/Radar
- SSS Anomaly of Various Spatial Scales Well Retrieved

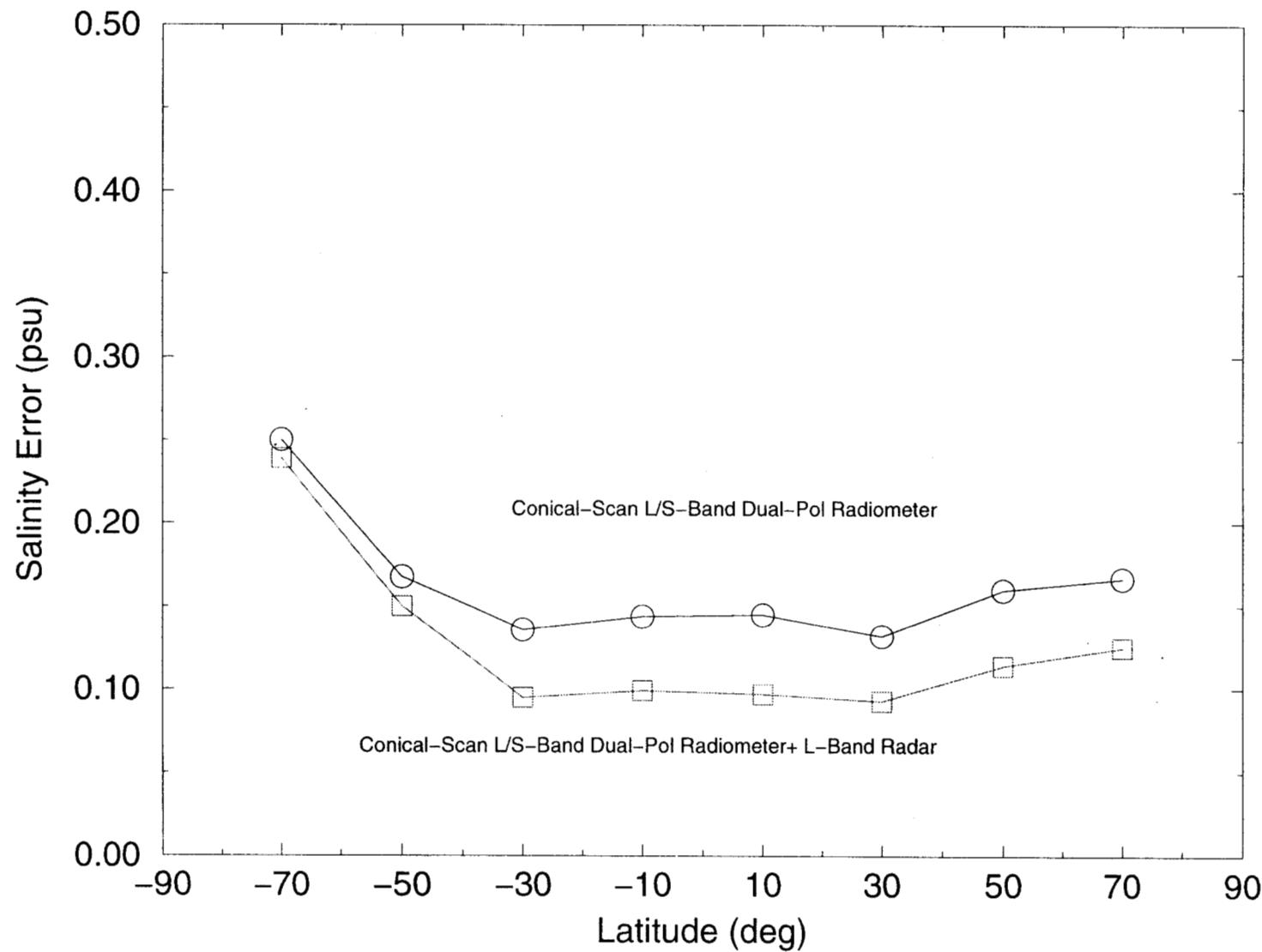
## Salinity Retrieval Simulation (7 Days of Data)

19960915–19960921



## Salinity Retrieval Simulation (4 Week Average)

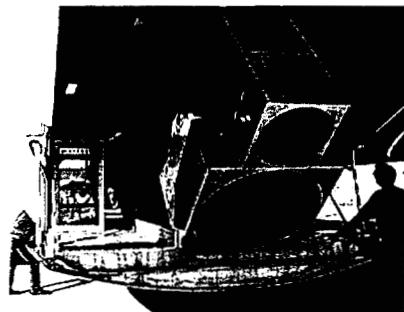
19960915–19961012



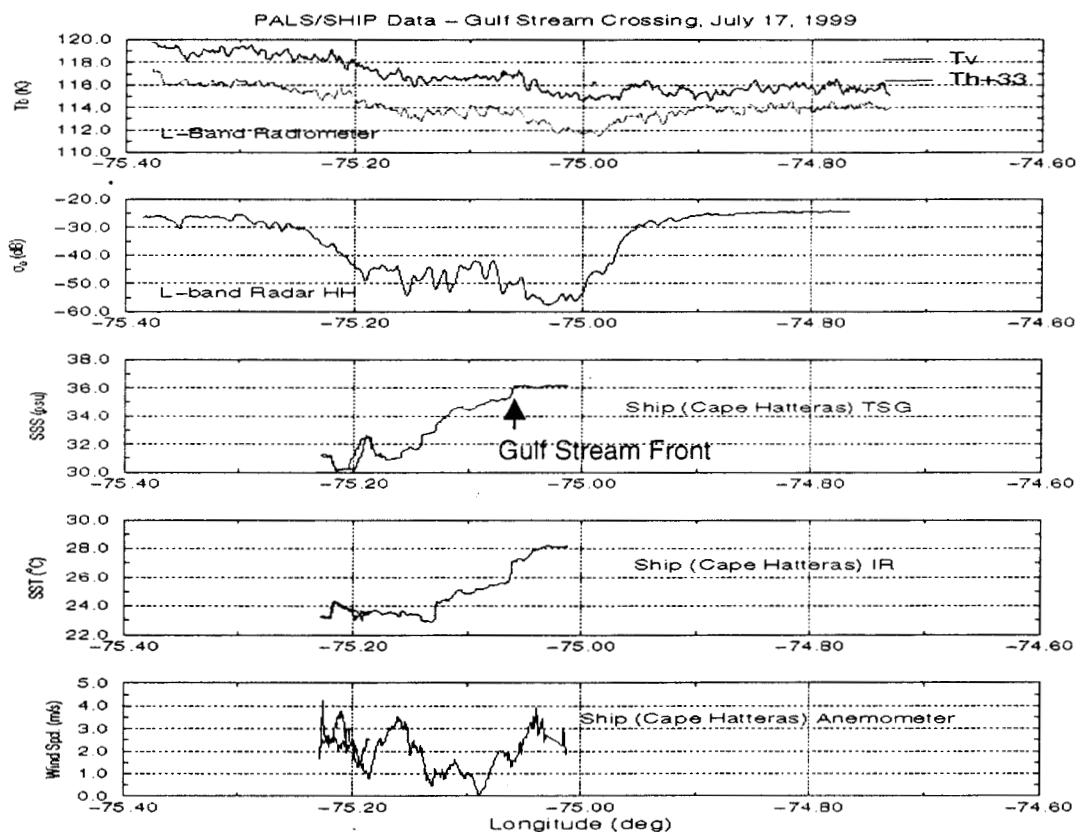
# JPL PALS/GULF STREAM OCEAN SURFACE SALINITY FLIGHTS IN 1999



NCAR C-130

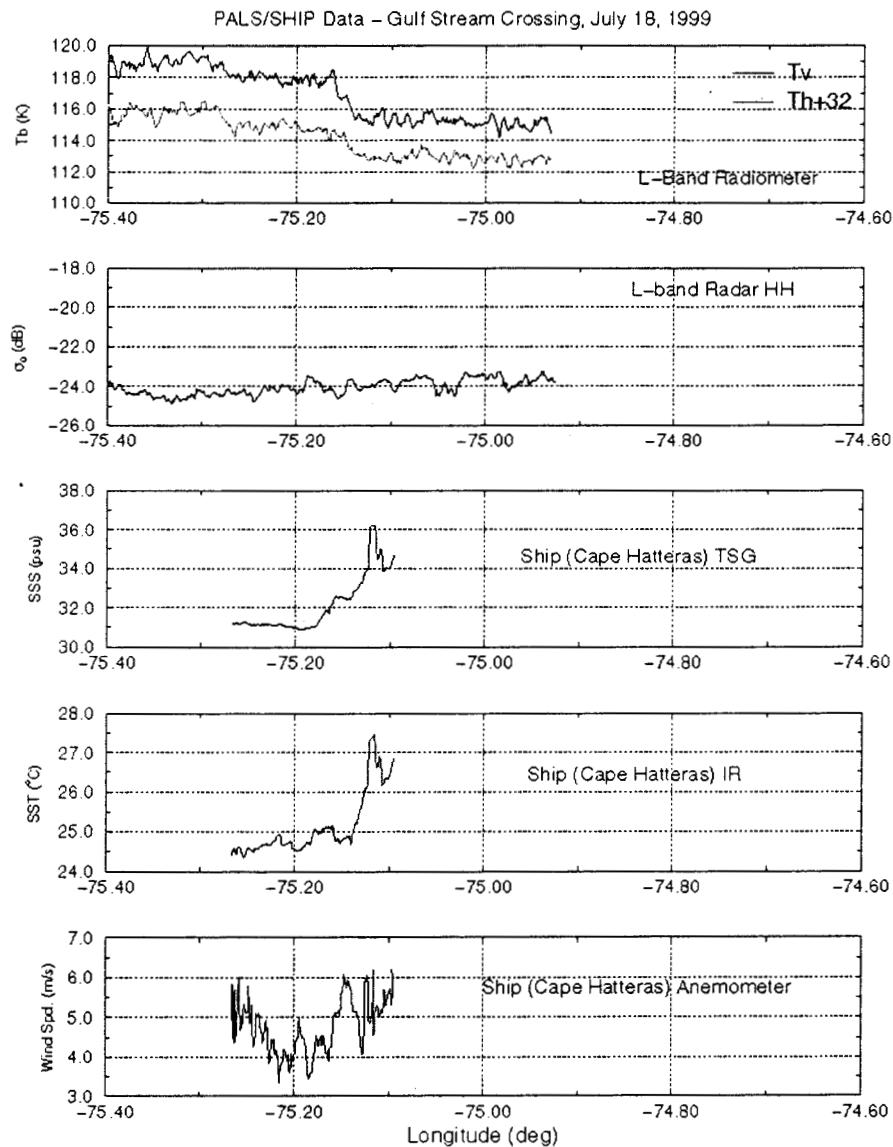


PALS ANTENNA ASSEMBLY ON C-130



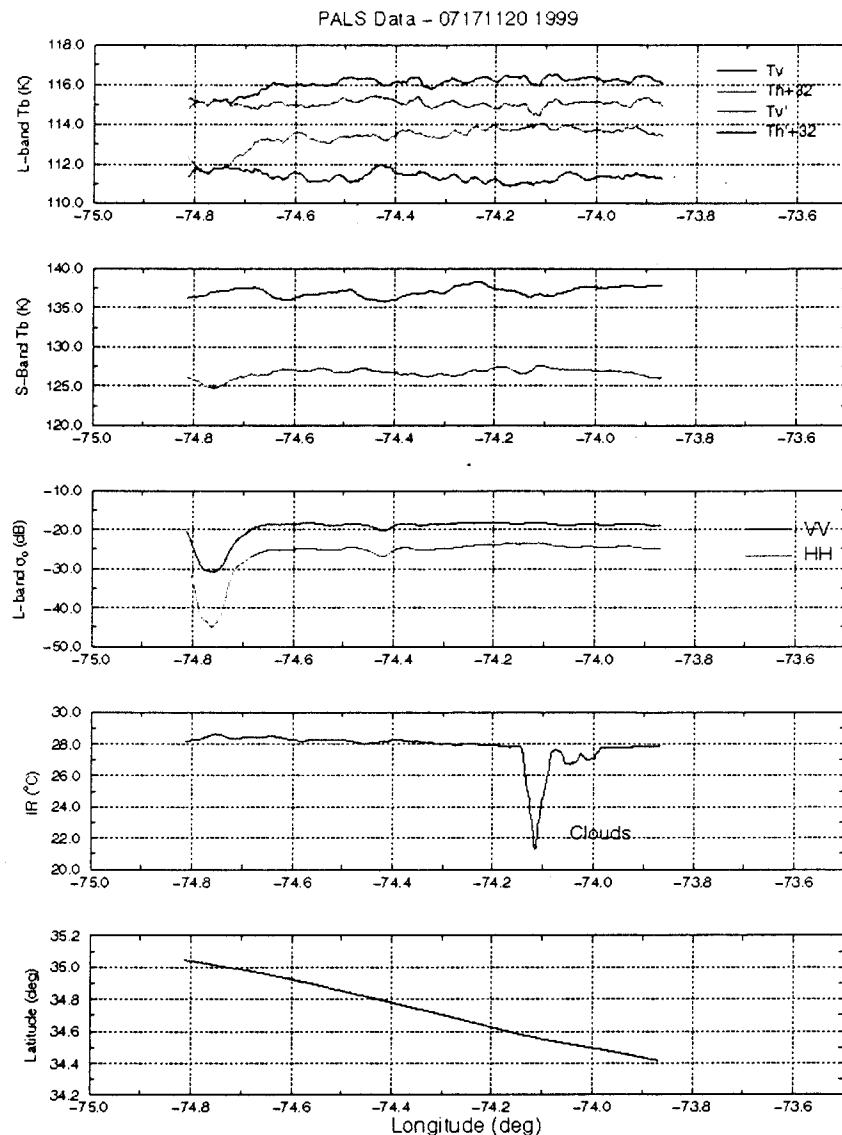
- In collaboration with GSFC, three successful PALS radiometer and radar flights across the Gulf Stream performed in July 17-19, 1999
  - 3 Kelvin L-band brightness temperature change consistent with 5 psu salinity change measured by Cape Hatteras
  - Surface roughness change detected by radar
- Ready for ocean field campaign in 2000

# PALS/GULF STREAM OCEAN SURFACE SALINITY FLIGHT ON 18 JULY 1999



- Flight on July 18 observed repeatable SSS signal in L-band Tb data across the Gulf Stream
- The surface appeared to be more uniform than that on July 17. Radiometer, radar, and ship data do not show a large change of surface roughness.

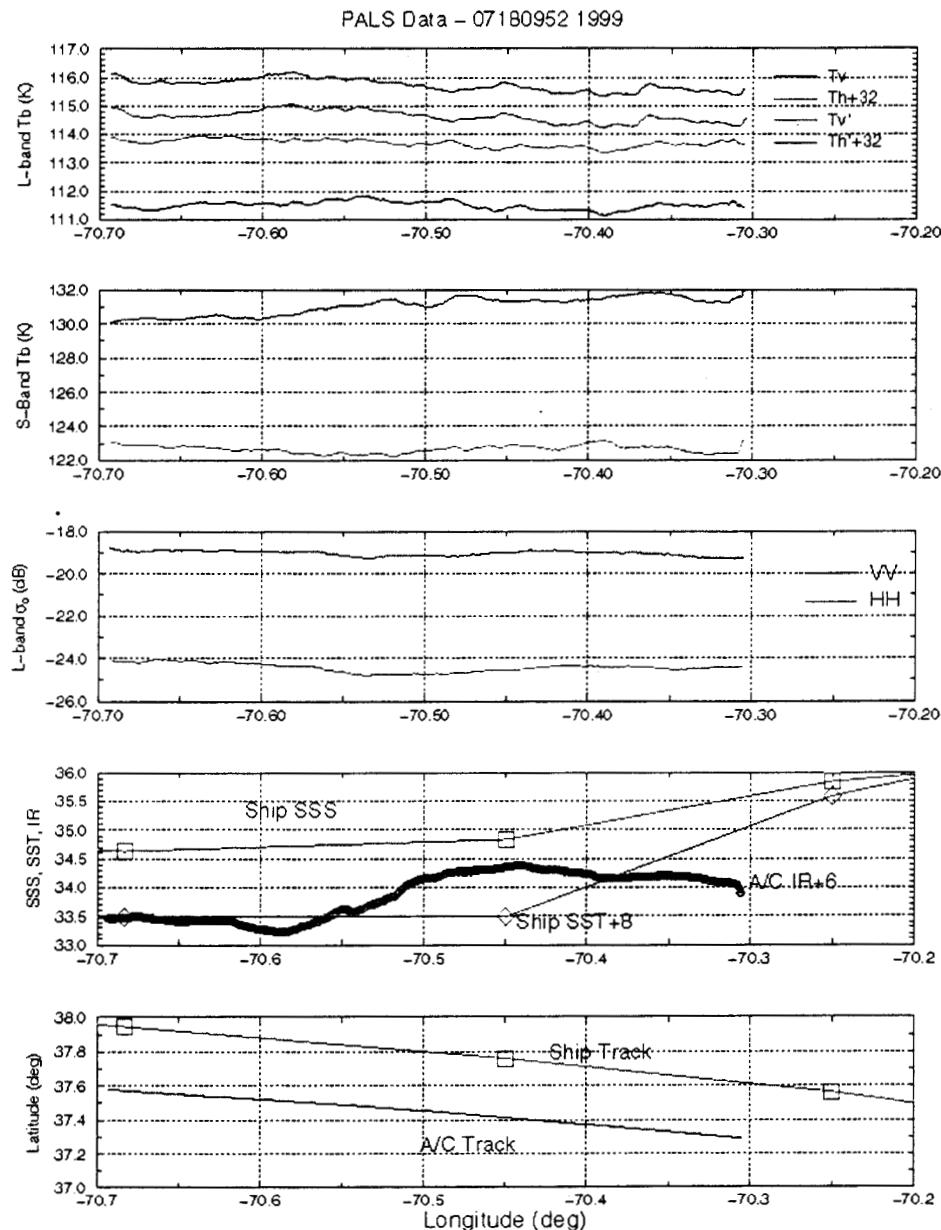
# PALS FLIGHTS NEAR GULF STREAM ON 17 JULY 1999



- The change of surface roughness is noticeable in the radiometer and radar data between 74.7W-74.8W longitude - about 1 Kelvin in L-band  $T_v$  and 2 Kelvin in L-band  $T_h$ .
- The excess brightness temperatures due to the surface roughness are successfully removed by using the radar data with an empirical linear correction ( $\Delta T_b = A \sigma_{hh}$ ).  $A=300$  for  $T_v$  and  $600$  for  $T_h$ . The values of  $A$  agree with the theoretical expectations that h-polarization is more sensitive to the surface roughness than v-polarization. The corrected brightness temperatures ( $T_v'$  and  $T_h'$ ) vary around their mean values by a standard deviation of about 0.2 K.



## PALS FLIGHT ADJACENT TO THE OLEANDER TRACK ON 18 JULY 1999



- L-band  $T_v$  data from the flight adjacent to the Oleander track show a drift of about 0.5-0.6 Kelvin from the beginning to the end of the flight line (west to east). This change appears to correspond to the SSS change of about 0.8 psu. Note that  $0.8 \text{ psu} \times 0.6 \text{ K/psu} = 0.48 \text{ Kelvin}$ .

## **SUMMARY**

- PROJECTED SALINITY MEASUREMENT ACCURACY MEETS THE SCIENCE REQUIREMENT FOR CONICAL SCANNER
  - CONICAL SCAN SUPERIOR TO CROSS-TRACK SCAN
- EXCELLENT CALIBRATION STABILITY REQUIRED
- EXCELLENT ANTENNA CHARACTERISTICS REQUIRED TO REDUCE THE IMPACT OF SOLAR RADIATION
- ACCURATE CORRECTION OF FARADAY ROTATION, SURFACE ROUGHNESS AND GALATIC RADIATION SOURCES REQUIRED
- AIRCRAFT PALS RADIOMETER/RADAR MEASUREMENTS IN JULY 1999 DEMONSTRATE FEASIBILITY



# **FEASIBILITY AND ERROR SOURCES FOR OCEAN SURFACE SALINITY MEASUREMENTS FROM SPACE**

## **APPENDIX**

### **L-BAND RADIO CLUTTER STUDY**

**KYOTO  
6-10 DECEMBER 1999**

# GALATIC RADIATION

- GALATIC RADIATION AT 1.4 GHZ

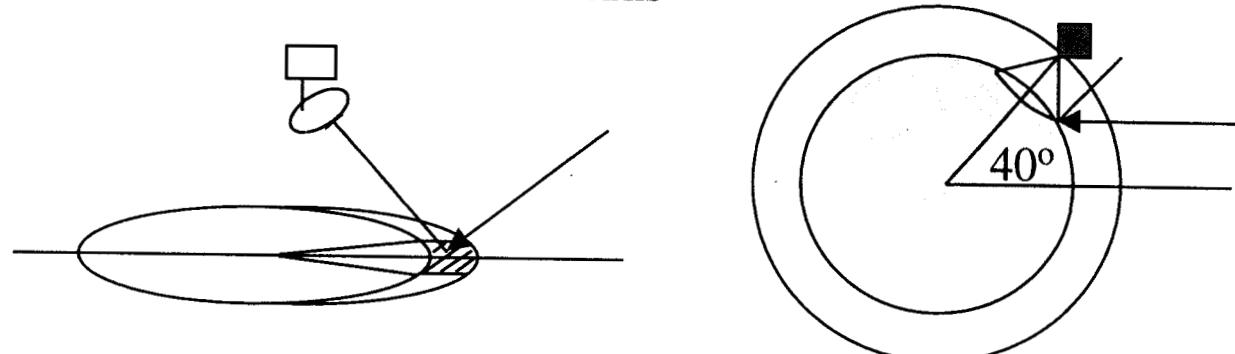
SOURCES	BRIGHTNESS	KNOWLEDGE (1%)
GALATIC CENTER	16 K	0.16K
GALATIC POLE	1 K	0.01K
BACKGROUND	2.7 K	0.027K

- DATA LOSS VERSUS THE ANGULAR EXTENT OF DATA FLAG

CASE	ANGULAR EXTENT	#BEAM WIDTH (3 DEG)	PERCENTAGE
1	20 DEG X 10 DEG NEAR THE GALATIC CENTER	6 X 3	$2 \times 20/360 \times 10/360 < 0.3\%$
2	10 DEG	+/- 1.5	$10/360 < 3\%$

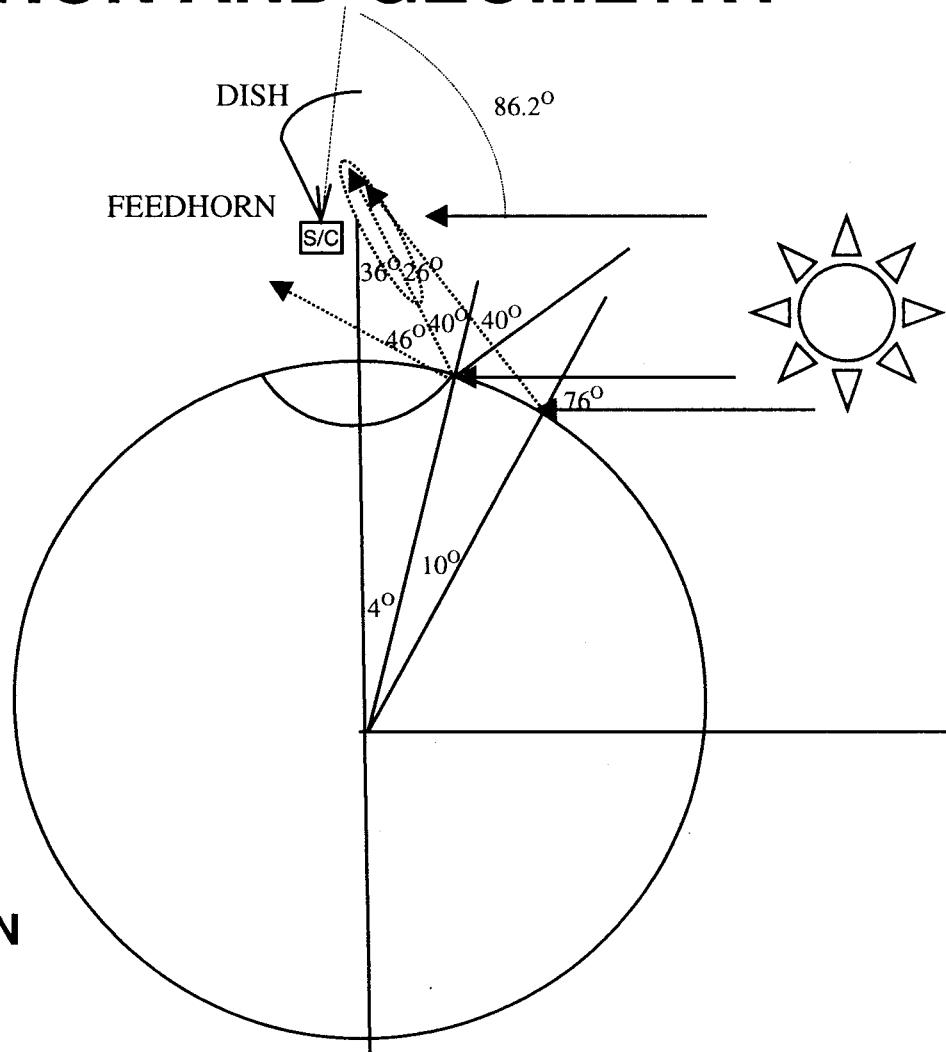
CASE 1: GALATIC CENTER IS ON THE ORBIT PLANE

CASE 2: GALATIC CENTER IS ON THE ORBITAL AXIS



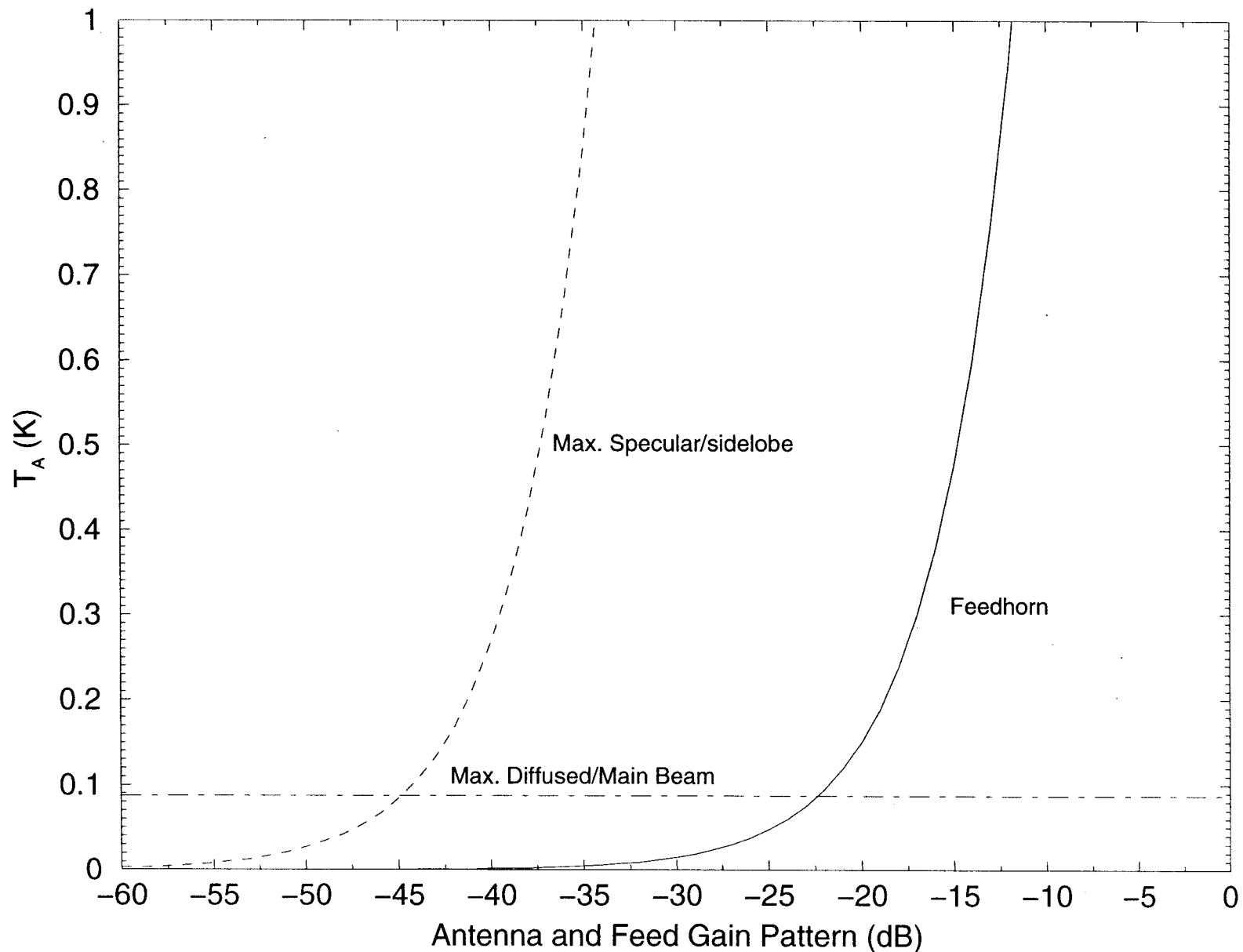
# SOLAR RADIATION AND GEOMETRY

- **6AM-6PM ORBIT**
  - ORBIT AXIS FACES THE SUN
- **WHEN THE ANTENNA BEAM IS LOOKING TOWARD THE SUN IN AZIMUTH**
  - SUN IS  $86.2^\circ$  FROM THE BORE SIGHT OF FEEDHORN
  - DIFFUSE SURFACE SCATTERING INTO THE MAIN BEAM
  - SPECULAR REFLECTION BY THE SURFACE INTO THE SIDELOBE AT  $26^\circ$  FROM THE BORE SIGHT



## Apparent Antenna Temperature of Solar Radiation

Sun  $T_B = 100,000$  K,  $D_{ant} = 37.5$  dB,  $D_{feed} = 15$  dB



# LUNAR RADIATION

- LUNAR RADIATION

WAVELENGTH	BRIGHTNESS ( $T_B$ )	SIZE OF LUNAR DISK ( $\Omega$ )
3.15 cm	180-200 K	0.215 DEG <sup>2</sup>
1.25 cm	200-300 K	

- APPARENT ANTENNA TEMPERATURE =  $T_B \Omega P_n / \Omega_A$

Pn	ANT. TEMP.
0 dB	< 30K
-30 dB	< 0.03K

- DATA LOSS VERSUS THE ANGULAR EXTENT OF DATA FLAG

CASE	ANGULAR EXTENT	#BEAM WIDTH (3 DEG)	PERCENTAGE
1	10 DEG X 5 DEG NEAR THE MOON	3 X 1.5	2X10/360X5/360 < 0.1%
2	10 DEG	+/- 1.5	10/360 < 3%

CASE 1: MOON IS ON THE ORBIT PLANE

CASE 2: MOON IS ON THE ORBITAL AXIS

# HYDROGEN LINE

- HYDROGEN LINE AT 1.4 GHz
  - BANDWIDTH: ~ 1 MHz
  - AVG. BRIGHTNESS: 50 K
- APPARENT ANTENNA TEMPERATURE

RECEIVER BANDWIDTH	TA	KNOWLEDGE (2%* TA)
25 MHZ	2K	0.04K
100 MHZ	0.5K	0.01K